§78. Magnetic Field Structure and Coil Design for Modular Heliotron (MH)

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Since to search for good confinement configurations compatible with the coil modularity and closed helical divertor is one of the most important issues for helical system, we are investigating the possible way to add a property of modularity to the continuous system[1].

On the basis of the LHD configuration, we can produce the modular heliotron with a coil gap angle Δ_{gap}. Here the following helical winding law is adopted: $\theta=(m/l)\phi+\alpha\sin[(m/l)\phi]$, where $\alpha=\alpha_{in}$ at $0<(m/l)\phi<\pi/2-\Delta_{gap}/2$ or $3\pi/2+\Delta_{gap}/2<(m/l)\phi<2\pi$ and $\alpha=\alpha_{out}$ at $\pi/2+\Delta_{gap}/2<(m/l)\phi<3\pi/2-\Delta_{gap}/2$. This is the same definition of continuous coil winding law when $\alpha_{in}=-\alpha_{out}=0$, $\Delta_{gap}=0°$. Here it is noted that these windings correspond to the optimized one from viewpoint of the good magnetic surface, clean divertor, high MHD equilibrium limit and tolerable neoclassical ripple transport.

Unlike the magnetic surfaces of this conventional heliotron like LHD (Fig.1(a)), the cross-sectional shape of the vacuum magnetic surfaces of the reference MH with $\alpha_{in}=-\alpha_{out}=0$, $\Delta_{gap}=8°$ are deformed to the rectangular shape and branching-off of divertor separatrix layers is induced. By other calculation, the reference MH systems with $\Delta_{gap}>2°$ are not tolerable for installing a divertor baffle plate. Even by applying the conventional pitch modulations ($\alpha_{in}=\alpha_{out}\neq0$) or elliptical, triangular shaping of winding support structure, it is difficult to obtain the good magnetic surfaces and the good divertor structure. Here, the good divertor structure means that the divergence of divertor field-line Poincare plot is small, the position of divertor legs is localized in poloidal direction, and its separatrix field lines are easily extracted to the outside of the coil system.

On the other hand, a modified MH with outside-plus/inside-minus modulated windings ($\alpha_{in}=-\alpha_{out}=-0.3$, $\Delta_{gap}=8°$) leads to reproduction of conventional heliotron configurations (Fig.1(b)), and gives rise to a better configuration with a larger plasma volume and a higher rotational transform. In this case, the divertor structure becomes clean and the stochastic region becomes thin. In the case that the plus/minus modulation is given by the continuity condition of the helical coil on gap, peripheral magnetic surface is distracted and the stochastic region becomes thick($\alpha_{in}=-\alpha_{out}=-0.369$).

A modified MH system with outside-plus/inside-minus modulation is effective at reproducing the good magnetic surfaces by adopting optimum modulation as a function of gap ($\alpha_{in}=-\alpha_{out}=-0.0375\times\Delta_{gap}(°)$).

In Fig.1, the magnetic surfaces are estimated by single filament coil model. Figure 2 shows the magnetic surface is estimated by finite coil size model. Here the coil width corresponds to $\Delta_{gap}/2=4°$. The field line structure in edge region for this model is as clean as the conventional continuos heliotron. Here it should be noted that $\Delta_{gap}/2=4°$ corresponds to the coil width which is necessary to construct a model reactor with $(R^0,B^0,a_p)=(15m,7T,2m)$ and $I=30A/mm^2$.

[1] Yamazaki K. et al, Nucl. Fusion **35** (1995) 1289.

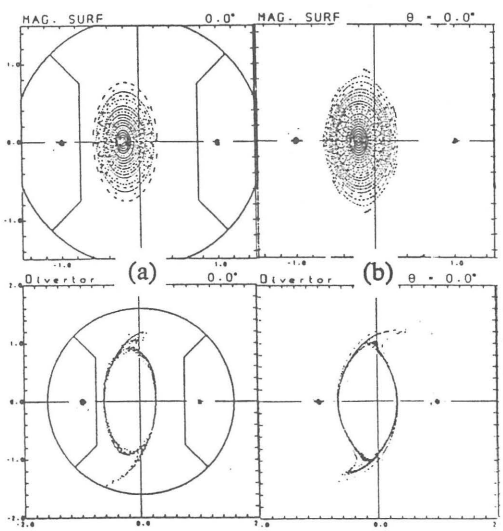

Fig.1 Vacuum magnetic surfaces and divertor layers for (a) the conventional heliotron, (b) the improved modular heliotron with $\alpha_{in}=-\alpha_{out}=-0.3$, $\Delta_{gap}=8°$.

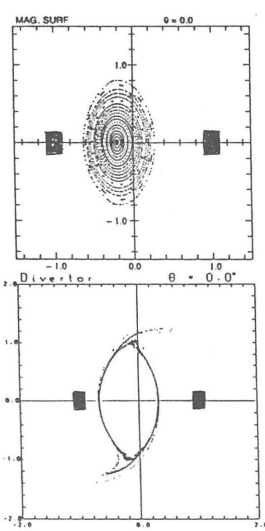

Fig.2 Vacuum magnetic surfaces and divertor layers for the improved modular heliotron with $\alpha_{in}=-\alpha_{out}=-0.3$, $\Delta_{gap}=8°$ for finite coil size model ($\Delta_{coil}=4°$).